



NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546

LEWIS

REPLY TO
ATTN OF: GP

November 6, 1970

TO: USI/Scientific & Technical Information Division
Attention: Miss Winnie M. Morgan

FROM: GP/Office of Assistant General Counsel for
Patent Matters

SUBJECT: Announcement of NASA-Owned U. S. Patents in STAR

In accordance with the procedures agreed upon by Code GP and Code USI, the attached NASA-owned U. S. Patent is being forwarded for abstracting and announcement in NASA STAR.

The following information is provided:

U. S. Patent No. : 3,508,402
Government or
Corporate Employee : U.S. Government
Supplementary Corporate
Source (if applicable) : NA
NASA Patent Case No. : XLE-00785

NOTE - If this patent covers an invention made by a corporate employee of a NASA Contractor, the following is applicable:

Yes ☐

No ☒

Pursuant to Section 305(a) of the National Aeronautics and Space Act, the name of the Administrator of NASA appears on the first page of the patent; however, the name of the actual inventor (author) appears at the heading of Column No. 1 of the Specification, following the words "... with respect to an invention of ..."

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Enclosure

Copy of Patent cited above

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BOILER FOR GENERATING HIGH QUALITY VAPOR

Filed Sept. 6, 1967

3 Sheets-Sheet 1

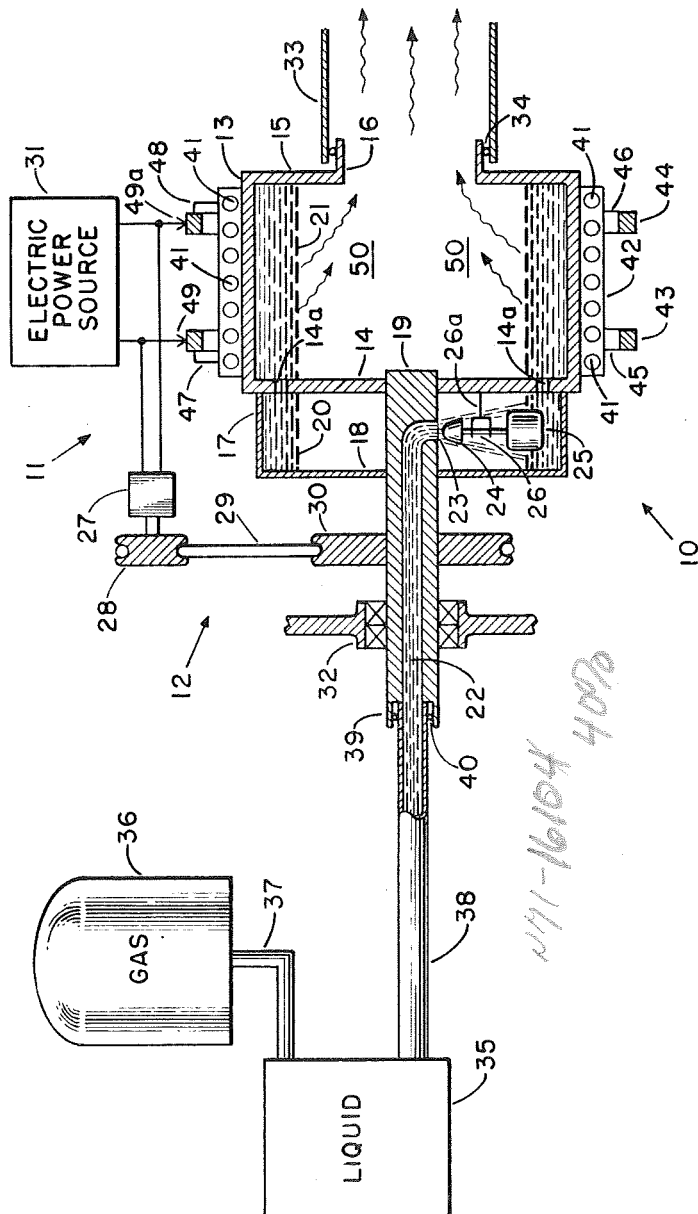


FIG. 1

271-16104 407a

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3 Sheets-Sheet 2

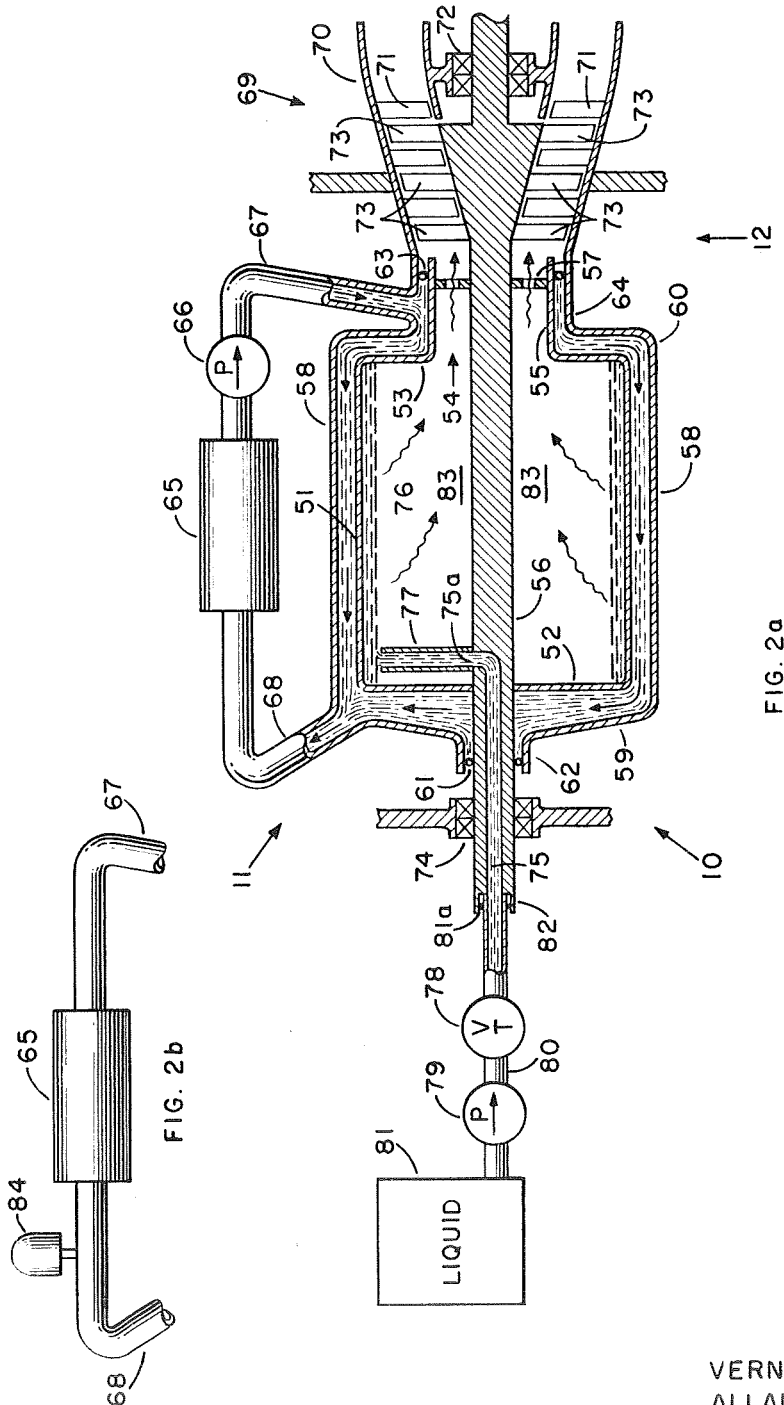


FIG. 2a

FIG. 2b

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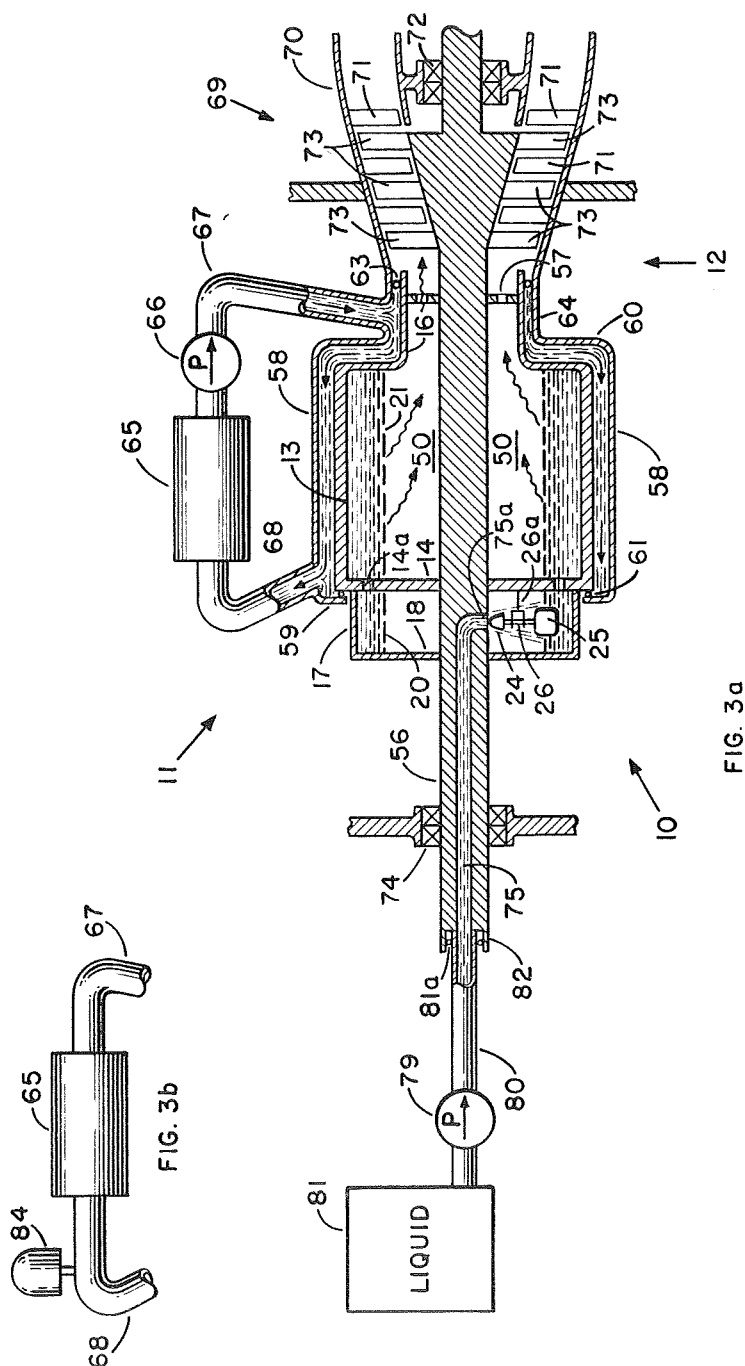
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BOILER FOR GENERATING HIGH QUALITY VAPOR

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3 Sheets-Sheet 3



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3,508,402

**BOILER FOR GENERATING HIGH
QUALITY VAPOR**

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15 Claims

ABSTRACT OF THE DISCLOSURE

A boiler for supplying high quality vapor from a liquid by imparting a high angular velocity to the liquid to form a liquid annulus in a heated, rotating drum whereby a sharp interface is produced between the liquid phase and the vapor phase in the drum.

The invention described herein was made by employees of the United States Government and may be manufactured and used by or for the Government for governmental purposes without the payment of any royalties thereon or therefor.

This invention relates generally to vapor generating systems for converting liquids to vapors and is directed more particularly to a boiler for supplying high quality vapor to a turbine motor.

It is desirable that vapor utilized to drive a turbine be of the highest quality. This means that the minimum possible number of liquid droplets is carried in the vapor. In systems such as Rankine cycle power systems where liquid metals are utilized to produce the vapor, liquid droplets in the vapor can cause severe erosion of the turbine blades.

With the advent of nuclear reactors as heat sources for Rankine cycle power generating systems, the forced flow, heat-exchanger type of "once-through" boiler has come into being. In this type of boiler, liquid metal is pumped to the boiler where it is vaporized by heat applied to the boiler. This heat, by way of example, may be supplied by a heated liquid metal surrounding the boiler and circulating through a nuclear reactor. The vapor produced in the boiler is directed through a turbine motor and then condensed and recirculated.

A number of flow instability problems have arisen as a result of using the forced flow, heat-exchanger type of "once-through" boiler. These problems are in the form of time-wise variations of pressure, temperature, flow rate of the fluid plus interactions with the feed system.

Past attempts at obtaining high quality vapor, particularly in systems utilizing liquid metals, have included boilers comprising one or more tubes, each containing either a helical or a twisted ribbon baffle. The baffles cause the liquid and vapor phases in the boiler tubes to follow a helical path. This influences the liquid and the vapor to separate so that the vapor can be delivered to the turbine.

The helical-baffle boiler tubes can provide a fairly high quality vapor, but the quality is not always as high as desired because of undesirable flow instabilities associated with Rankine cycle systems for space applications. Furthermore, this type of boiler causes a substantial pressure drop because of the baffles. Additionally, its operation is often influenced by gravitational fields and orientation.

Accordingly, it is an object of the invention to provide an improved boiler which is capable of supplying vapor uniformly at a very high quality.

It is another object of the invention to provide a boiler which produces a sharp interface or separation

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between the liquid phase and the vapor phase therein in spite of high heat input rates to the boiler.

It is a further object of the invention to provide a boiler which has relatively little pressure drop.

Still another object of the invention is to provide a boiler, the operation of which is substantially unaffected by gravitational fields or orientation.

It is yet another object of the invention to provide a boiler in which the flow of liquid and vapor is steady.

Other objects and advantages of the invention will become apparent from the following description and accompanying drawings in which:

FIG. 1 is a cross-sectional view of a two-stage boiler;

FIG. 2a is a cross-sectional view of a second embodiment of the invention in which the boiler is adapted for rotation with the rotor of a turbine motor;

FIG. 2b shows a modification to the structure of FIG. 2a;

FIG. 3a is a cross-sectional view of a boiler embodying certain parts of the structures of FIGS. 1 and 2; and FIG. 3b shows a modification to the structure shown in FIG. 3a.

Referring now to FIG. 1, the embodiment of the invention shown there comprises a boiler 10, boiler heating means 11 and boiler drive means 12. The boiler comprises a drum 13 having an end wall 14 and an end wall 15, the latter including a vapor outlet which is concentric with the drum axis. The vapor outlet is formed by an axially, outwardly extending annular flange 16 disposed in the end wall 15.

Adjacent to and concentric with the drum 13 there is provided a drum 17 having an end wall 18. A shaft 19 extends through the walls 18 and 14 to support the drums 13 and 17 for rotation. In order to form a liquid annulus 20 against the interior surface of the drum 17 and to form a liquid annulus 21 against the interior surface of the drum 13, a passage 22 is provided in the shaft 19 and opens into a port 23 axially positioned between the walls 18 and 14. The flow of liquid entering the drum 17 is controlled by a plug 24 actuated by a float 25 by means of a rod 26. To limit movement of the plug 24 and the float 25 to a radial path, a yoke 26a mounted on the wall 14 aligns the rod 26. The port 23, together with the plug 24, float 25 and the rod 26 serve as a liquid flow rate control means for the boiler 10. Thus, the drum 17 may be considered as a flow rate control stage of the boiler 10 while the drum 13 is the boiler stage.

To the end that the drum 13 will be rotated at a high rate of speed whereby a liquid annulus 21 is formed therein, the drum driving means 12 is provided. The driving means may include an electric motor 27 having a pulley 28 connected through a belt 29 to a pulley 30 on the shaft 19. Adjacent to the pulley 30, a bearing 32 is provided to support the shaft 19. A similar bearing (not shown) may be provided at some other point on the shaft 19 for more support. The vapor conduit 33 fits over the annular flange 16 in telescoping fashion and an annular seal 34 is disposed therebetween.

In order to supply liquid to the port 23 under pressure, there is provided a liquid container 35, the upper end of which is connected to a tank of pressurized gas 36 through a gas line 37. A stationary pipe 38 extends from the lower end of the liquid container 35 into a cup formed by a cylindrical flange 39 disposed at one end of the shaft 19. A suitable annular seal 40 is disposed between the cylindrical flange and the pipe 38 to prevent loss of the liquid flowing in the pipe 38 and the passage 22. The pipe 38 together with the passageway 22 and the port 23 comprise a liquid flow path.

To the end that heat will be applied to the drum 13 to vaporize a liquid annulus 21 contained therein, insulated heater elements 41 are disposed around the exterior of the drum in a thermally conducting material 42. Electric current is supplied to the heater elements 41 from a pair of metal rings 43 and 44 disposed outside of the heater elements and supported by insulators 45 and 46. The rings 43 and 44 are connected to the heater elements 41 by leads 47 and 48, respectively. To deliver electric power to the heater elements 41, brushes 49 and 49a ride on the rings 43 and 44, respectively, as the drum 13 rotates, the brushes being connected to the electric power source 13.

In operation, the motor 27 drives the shaft 19 together with the drums 13 and 17 mounted thereon at a high rate of rotation. Heat is applied to the exterior of the drum 13 by the heating elements described previously.

The pressurized gas in the tank 36 forces the liquid in the container 35 to flow through the pipe 38 and the passageway 22 to the port 23. When the thickness or depth of the liquid annulus 20 is of a prescribed value, the plug 24 will be forced against the port 23 by the float 25, thus preventing liquid from entering the drum 17. However, when the depth or thickness of the liquid annulus 20 drops below the prescribed value, the rotating float 25, because of centrifugal force, pulls the plug 24 away from the port 23 allowing liquid to spray into the drum 17.

Since the port 23 rotates about the axis of the drums 13 and 17, a slight angular velocity is imparted to the liquid entering the drum 17. Consequently, the liquid travels radially away from the axis and merges from the liquid annulus 20. An additional small angular velocity is provided to the liquid annulus 20 due to friction of the drum 17.

In order to establish a liquid annulus 21 having an inner surface, the diameter of which is equal to the diameter of the inner surface of the liquid annulus 20, a plurality of small conduits 14a are provided in the wall 14 radially outward from the inner surface of the liquid annulus 20. As viewed in FIG. 1, the liquid moves axially toward the right from the drum 17 into the drum 13 via the conduits 14a. The conduits 14a impart angular velocity to the liquid so that the slippage or difference between the angular velocity of the liquid annulus 21 and the rotation rate of the drum 13 is negligible. Thus, the conduits 14a together with the surface friction in drum 17 serve as angular velocity imparting means for the boiler liquid.

Ordinarily, when a liquid is heated to obtain vapor, the liquid undergoes boiling in which the surface becomes very turbulent. Such turbulence causes liquid droplets to be dispersed in the vapor. Consequently, where high quality vapor is desired, a sharp interface must be produced between the liquid and the vapor.

In the instant invention, the annulus 21 is heated by the heater elements 41 disposed around the outside of the drum 13 to boil the liquid forming the annulus 21. However, because of the high angular velocity of the annulus 21 a sharp interface is advantageously produced between the liquid annulus and the vapor 50 whereby high quality vapor results. The vapor is created in the boiling liquid annulus 21 near the heated drum 13 and at the interface, and is centrifuged radially inward toward the center of rotation. This vapor 50 then travels axially to the right, as viewed in FIG. 1, and flows into the fixed vapor conduit 33 which directs it to a turbine or other suitable device.

From the foregoing description, it will be seen that the rotating boiler of the instant invention provides a continuous flow-through. That is, liquid enters at one end, flows axially toward the other end in an annulus, is vaporized and continues flowing the same axial direction to the point where it is to be utilized.

It is desirable to rotate the drum 13 at the highest possible speed in order that a sharp interface will be produced between the liquid and vapor phases in the drum. High speed rotation also generates high artificial gravities whereby operation of the boiler is substantially unaffected by orientation to earth gravity or by gravitational fields

other than that of the earth. Of course, the rotational speed of the drums 13 and 17 must be such that the hoop-stress and vibrational limits of the drums are not exceeded.

It will be understood by those skilled in the art that the rotational speed required to produce a sharp interface between the liquid and the vapor decreases as the heat applied to the drum decreases. Similarly, the rotational speed of the drum may be reduced as its diameter is increased. Where the liquid used to generate vapor is water and where heat is applied to the boiler at the rate of 88,000 B.t.u. per hour, ft.², it has been found that rotating the drums 13 and 17 at a speed to produce 400 gravities creates a smooth continuous interface.

As the number of gravities is increased, the boiling heat flux can be increased by a ratio proportional to the fourth root of the number of artificial gravities. Thus, for 10,000 artificial gravities, the heat flux can be 10 times as much as at 1 gravity.

Referring now to FIG. 2, there is shown an embodiment of the invention which is particularly well suited for use in a Rankine cycle power system. As in the structure of FIG. 1, the embodiment of the invention illustrated in FIG. 2 comprises a boiler section 10, boiler heating means 11 and boiler driving means 12. The boiler section 10 comprises a drum 51 having a first end wall 52 and a second end wall 53 having a vapor outlet opening 54 therein. The vapor outlet 54 is formed by a cylindrical flange 55 which extends axially outward from the end wall 53. The drum 51 is carried on a rotatable shaft 56 which extends through the end walls 52 and 53. An aperture plate 57 disposed between the cylindrical flange 55 and the shaft 56 maintains the axial alignment of the drum 51 by preventing radial movement of the cylindrical flange 55.

The boiler section 10 is completed by a stationary cylindrical jacket 58 disposed coaxially around the drum 51, the jacket 58 having end walls 59 and 60. An annular seal 61 is disposed between a cylindrical flange 62 which extends outwardly from the end wall 59 coaxially with the shaft 56. Similarly, an annular seal 63 is disposed between the cylindrical flange 55 of the drum 51 and a cylindrical, outwardly extending flange 64 which extends axially outward from the end wall 60 coaxially with the cylindrical flange 55.

In order to heat the drum 51, a suitable heating fluid or liquid such as sodium, potassium or lithium is heated to high temperature by a heater 65, as for example a nuclear reactor, and forced by a circulating means such as a pump 66 through a pipe 67 into the space between the cylindrical flange 55 and the cylindrical flange 64. The high temperature fluid moves axially toward the left, as view in FIG. 2, in the space between the drum 51 and the cylindrical jacket 58. A circumferential couette flow is also induced in the heating fluid by the rotation of the drum 51. Because of the shear (and secondary flow) in the induced couette flow, a high convection heat-transfer coefficient is advantageously established at the outer surface of the drum 51. Additionally, rotation of the drum creates a radial density gradient in the heating fluid, sending the hotter fluid elements to the outer surface of the drum 51. This increases the heat transfer. The heating fluid then passes through a pipe 68 back to the heat source where it is reheated and recirculated through the path just described.

The circumferential couette flow mentioned previously produces a self-pumping action to circulate the heating fluid. This self-pumping action may be great enough under certain conditions that the pump 66 is no longer required. By adding suitable vanes to the exterior surfaces of the drum 51, the self-pumping action is substantially increased.

In the embodiment of FIG. 2 a turbine motor 69 serves as the drum driving means. The turbine motor 69 comprises an outer housing 70 which is contiguous with the

cylindrical flange of the jacket 58. Stator blades 71 extend radially inward from the housing 70. The shaft 56 on which the drum 51 is carried extends into the turbine housing 70 and is supported in a bearing 72. The turbine motor 69 is completed by rotor blades 73 which extend radially outward from the shaft 56. The shaft 56 is also supported by a bearing 74 adjacent to the cylindrical flange 62 of the end wall 59 of the jacket 58.

To the end that liquid will be supplied to the interior of the drum 51, an axle passageway 75 is provided in the shaft 56 and extends inwardly of the end wall 52 of the drum 51 where it terminates as a port 75a in the shaft 56. In order to impart an angular velocity to the liquid entering the drum 51 whereby a liquid annulus 76 will form on the interior surface of the drum 51, a tube 77 extends radially outward from the port 75a in the shaft 56. The length of the tube 77 is such that the end of the tube remote from the port 75a is adjacent to but not touching the surface of the drum 51. If desired, the tube 77 may be replaced by a plurality of nozzles communicating with the passageway 75.

The flow rate of the liquid being supplied to the interior of the drum 51 is controlled by a throttle valve 78 and a pump 79. The throttle valve 78 and the pump 79 are disposed in a pipe 80 which connects a source of liquid 81 such as sodium or potassium to the axial passage 75 of the shaft 56. As is well known to those skilled in the turbine art, in Rankine cycle systems the vapor leaving the turbine is condensed and recirculated to the boiler. The source of liquid 81 referred to herein is intended to include the condenser and other ancillary recirculating equipment of a Rankine cycle system.

Leakage of the liquid where the pipe 80 abuts the shaft 56 is prevented by an annular seal 81a disposed between the pipe 80 and a cylindrical flange 82 formed on the end of the shaft 56. Similarly, a face-seal could be used in this and other seal installations.

Operation of the boiler illustrated in FIG. 2 will now be described. A fluid, heated by the nuclear reactor 65, is forced by the pump 66 into the space between the drum 51 and the jacket 58 by way of the pipe 67. The heated fluid flows axially and circumferentially as described previously, and passes over the outer surface of the drum 51. The fluid then flows through the pipe 68 back to the nuclear reactor 65.

It will be assumed, for purposes of explanation of the generation of vapor in the drum 51, that the drum and the shaft 56 together with the rotor blades 73 are rotating at high speed. The pump 79 forces liquid coming from the condenser into the liquid annulus 76 through a liquid flow path comprising the pipe 80, the throttle valve 78, the passageway 75 in the shaft 56 and the tube 77. As the liquid passes through the tube 77, an angular velocity is imparted to the liquid because of the high speed rotation of the shaft 56. The liquid then flows out of the tube 77 into the liquid annulus 76.

The flow rate of the liquid being delivered to the liquid annulus 76 is controlled by the throttle valve 78 and the pump 79. The throttle valve 78 is adjusted so that the liquid flow is just sufficient to replenish the liquid being converted into vapor 83 by the heat applied to the drum 51 by the heating fluid.

The vapor 83 moves toward the right through the outlet opening 54, the aperture plate 57 and the turbine housing 70. The movement of the vapor through the turbine housing 70 produces rotation of the rotor blades 73 thereby driving the turbine and shaft 56 and the drum 51. Because the shaft 56 is extended into and is part of the turbine motor 69, the drum 51 is rotated at extremely high speed on the order of 10,000 to 20,000 r.p.m. with all the advantages set forth above.

As in the case of the drums 13 and 17 of FIG. 1, the rotational speed of the drum 51 must be restricted so that the hoop-stress limits are not exceeded. Advantageously, in the embodiment of FIG. 2, the drum may be

operated at a speed greater than normally permitted. This is accomplished by utilizing the pump 66 to force the heating fluid into the space between the drum 51 and the jacket 58 under increased pressure. The pressure thus applied to the outside of the drum 51 relieves the hoop-stress limits so that a higher speed of rotation may be realized.

Referring to FIG. 2b, there is shown a modification to the structure of FIG. 2a. As shown in FIG. 2b, the pump 66 has been eliminated and circulation of the heating fluid is achieved by the self-pumping action resulting from rotation of the drum. In order to pressurize the space between the drum 51 and the jacket 58, a pneumatic dome is inserted in the pipe 68 between the jacket 58 and the heat source 65.

Referring now to FIG. 3 there is shown a vapor generating system which utilizes the rotating drums 13 and 17 of FIG. 1 in lieu of the drum 51 shown in FIG. 2. The numerals identifying parts within the drums 13 and 17 of FIG. 3 are identical to numerals used to identify corresponding parts in FIG. 1 with two exceptions, namely, numeral 75a identifying the port in the shaft 56 and numeral 57 identifying an apertured plate now shown in FIG. 1. Similarly, like parts in FIGS. 2 and 3 are identified by like numerals.

The operation of the drums 13 and 17 is substantially the same as in the structure of FIG. 1. Likewise, the circulation of heating fluid around the drum is substantially as described in relation to FIG. 2. As in the case of FIG. 2, vapor passes out of the drum causing rotation of the turbine blades 73 carried on the shaft 56 which extends into the turbine motor 69. Since the drums 13 and 17 are carried on the shaft 56, they rotate at high speed with the turbine rotor.

FIG. 3b illustrates the same modification to the heating means of FIG. 3a that is shown in FIG. 2b relative to FIG. 2a.

It will be understood that changes and modifications may be made to the foregoing structures without departing from the spirit and scope of the invention as set forth in the claims appended thereto.

What is claimed is:

1. In a vapor generating system including a source of liquid, in combination,
 - a drum supported on a shaft for rotation therewith about an axis passing through the center of the drum parallel to its surface of revolution, said drum including an outlet for the vapor,
 - driving means connected to said drum to drive the same at a high rotational speed,
 - angular velocity imparting means connected in liquid receiving relationships to the source of liquid and disposed inside the drum to impart an angular velocity to the liquid annulus that is formed against the interior surface of the drum,
 - heating means comprising a stationary jacket disposed outside of the drum in space relationship thereto, a heat source, means for connecting the heat source to the jacket in fluid conducting relationship whereby a heating fluid is circulated through the heat source and the space between the jacket by the self-pumping action of the drum, and
 - liquid flow rate control means disposed between the source of liquid and the drum to maintain the depth of the liquid annulus at a prescribed value independent of the vaporization rate and rotative speed.
2. The vapor generating system of claim 1 wherein vanes are disposed on the exterior surface of the drum to increase circulation of the heating fluid and wherein a pneumatic dome is disposed between the heating means and the jacket to pressurize the space between the jacket and the drum whereby the hoop-stress limits of the drum are relieved.
3. The vapor generating system of claim 1, the shaft on which the drum is mounted having an axial passage

in one end communicating with a port in the shaft, said port opening into the drum; said flow rate control means comprising a first pump and a throttle valve connected between the source of liquid and said one end of the shaft; and said angular velocity imparting means comprising a tube extending radially from the port in the shaft.

4. The vapor generating system of claim 2 in which the driving means comprises a turbine motor connected in vapor receiving relationship to the drum and including a rotor having a direct mechanical connection to the other end of the shaft on which the drum is carried.

5. In a vapor generating system including a source of liquid, in combination,

a drum supported on a shaft for rotation therewith about an axis passing through the center of the drum parallel to its surface of revolution, said drum including an outlet for the vapor,

said drum being divided into first and second sections by a wall having a plurality of conduits therein adjacent to the interior surface of the drum, the shaft on which the drum is carried having a port opening into said first drum section and communicating with an axial passage in the shaft, said shaft being connected to the source of liquid, the heating means being disposed around said second drum section,

driving means connected to said drum to drive the same at a high rotational speed,

angular velocity imparting means connected in liquid receiving relationships to the source of liquid and disposed inside the drum to impart an angular velocity to the liquid annulus that is formed against the interior surface of the drum,

heating means disposed outside of the drum to heat the drum and the liquid annulus whereby vapor is produced, and

liquid flow rate control means disposed between the source of liquid and the drum to maintain the depth of the liquid annulus at a prescribed value independent of the vaporization rate and rotative speed.

6. The structure set forth in claim 5 in which the flow rate control means comprises a plug positioned in the port in the shaft, a rotating float operatively connected to the plug, and alignment means connected to the plug and the float to restrict the plug to radial movement within the first drum.

7. The structure set forth in claim 6 in which the heating means comprises a stationary jacket disposed outside of the drum in space relationship thereto, a heat source, means for connecting the heat source to the jacket in fluid conducting relationship whereby a heating fluid is circulated through the heat source and the space between the jacket by the self-pumping action of the drum.

8. The structure set forth in claim 5 in which the driv-

ing means is a turbine motor connected in vapor receiving relationship to the second drum section, said turbine motor including a rotor comprising rotor blades carried on a portion of the rotatable shaft extended into the turbine motor.

9. The structure as set forth in claim 7 wherein vanes are disposed on the exterior surface of the drum to increase circulation of the heating fluid and wherein a pneumatic dome is disposed between the heating means and the jacket to pressurize the space between the jacket and the drum whereby the hoop-stress limits of the drum are relieved.

10. The structure set forth in claim 7 in which the heat source is a nuclear reactor.

11. The structure of claim 7 in which a second pump is disposed between the heat source and the jacket to circulate the heating fluid and to pressurize the space between the jacket and the drum whereby the hoop-stress limits of the drum are relieved.

12. The structure set forth in claim 8 in which the heating means comprises a stationary jacket disposed outside of the drum in space relationship thereto, a heat source, means for connecting the heat source to the jacket in fluid conducting relationship whereby a heating fluid is circulated through the heat source and the space between the jacket by the self-pumping action of the drum.

13. The structure set forth in claim 12 in which vanes are disposed on the exterior surface of the drum to increase circulation of the heating fluid and wherein a pneumatic dome is disposed between the heating means and the jacket to pressurize the space between the jacket and the drum whereby the hoop-stress limits of the drum are relieved.

14. The structure set forth in claim 12 in which a second pump is disposed between the heat source and the jacket to circulate the heating fluid and to pressurize the space between the jacket and the drum whereby the hoop-stress limits of the drum are relieved.

15. The structure set forth in claim 13 in which the heat source is a nuclear reactor.

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U.S. Cl. X.R.

122—11